Spatial Soliton-like Similaritons and Soliton Amplification

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Self-similarity has always been one of the central themes in a variety of physics fields, ranging from hydrodynamics and turbulence [1] through plasma physics [2] to nuclear physics [1]. Surprisingly, however, it has only recently attracted attention of nonlinear optics community. This interest has been reinforced by recent results on self-similar dynamics of stimulated Raman scattering [3], asymptotic behavior of parabolic intensity profile pulses in fiber amplifiers [4, 5], and Cantor-set fractal formation in nonlinear optical systems [6]. To give a unified description of these diverse phenomena involving nonlinear self-similar waves, the term similariton was coined in Ref. [7] to refer to such waves. To our knowledge, however, with a few exceptions [6] the interest in optical similaritons has so far focused on *temporal* similaritons.

In this work, we report a discovery of new families of bright and dark (1 + 1)D *spatial* similaritons, supported by planar, graded-index nonlinear waveguide amplifiers. The linear part of the material refractive index of such nonlinear waveguide amplifiers is taken to be $n_l = n_0 + n_1 x^2$. The linear refractive index inhomogeneity is along the x-direction; the positivity of the coefficient $n_1 > 0$ implies that in the low intensity limit, the graded-index waveguide acts as a linear defocusing lens. The phase of each novel similariton has a linear static chirp. The intensity profile of any such bright or dark similariton is the same as that of the corresponding soliton propagating in a planar, homogeneous passive waveguide with the same nonlinearity. Thus a connection between spatial solitons and similaritons is revealed.

We also propose to use the discovered similaritons to amplify and focus spatial solitons in the futuristic all-optical networks. The proposed device is expected to operate as follows. A linear phase chirp is imprinted on a fundamental bright (dark) spatial soliton with an appropriate phase mask, placed immediately at the entrance to a graded-index waveguide amplifier. Provided the gain strength per unit length g satisfies the matching condition $g = \sqrt{2n_l}$, the entering phase-chirped spatial soliton behaves as a similariton on propagation inside the amplifier. The amplified similariton emerges at the exit of the amplifier where another phase mask is used to remove the phase chirp, and the resulting beam is an amplified and focused bright (dark) soliton which can be utilized in all-optical networks. The gain can be kept constant along the waveguide by using a counter-propagating pump of adjustable magnitude to satisfy the just mentioned constraint on the magnitude of g.

It only remains to estimate the practicality of the device. To achieve a 10 dB gain, say, i.e., the order of magnitude soliton amplitude amplification at the end of a waveguide of length $L_w = 5$ cm, $e^{gLw} = 10$, we need the gain strength $g \cong 0.4$ cm^{-1}, which is attainable in eurbium-doped waveguides, for example. In order to guarantee the fulfillment of the condition $g \cong \sqrt{2n_l}$, one must have a grading with $n_1 \cong 0.05$ cm^{-2}, which implies that the transverse spatial scale, $w_0 = (2k_0^2 n^1)^{-1/4}$, associated with the "linear defocusing lens" of the graded-index waveguide, is estimated to be $w_0 \cong 100$ μm. It follows that if we take the soliton width in the source plane to be equal to w_0, the soliton width decreases from 100 μm to 10 μm, while the amplitude is amplified by a factor of 10 inside such an amplifier. All these quantitative estimates testify to the practicality of the proposed device.

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